The 3rd International Conference on Transportation Information and Safety, June 25 – June 28, 2015, Wuhan, P. R. China

A Research on AIS-based Embedded System for Ship Collision Avoidance

Dejun CHEN
Hubei Inland Shipping Technology Key Laboratory
Wuhan 430063, China
School of Information Engineering
Wuhan University of Technology
Wuhan 430070, China
mrchendj@163.com

Chu DAI
School of Information Engineering
Wuhan University of Technology
Wuhan 430070, China
dai_chu@163.com

Xuechao WAN
School of Information Engineering
Wuhan University of Technology
Wuhan 430070, China
wanxuechaojob@163.com

Junmin MOU
Hubei Inland Shipping Technology Key Laboratory
Wuhan 430063, China
moujm@whut.edu.cn

***Abstract*—This paper uses the data provided by AIS as the sources of information and combines the actual needs for ship collision avoidance perception. Considering the major factor for ship collision impact, a mathematical model of risk evaluation is established for embedded system, and a new design of AIS-based embedded system for ship collision avoidance is proposed. By utilizing an ARM platform, the system has realized many decision support functions, such as intelligent analysis, forewarning prompt, operation suggestion, and data backtracking, displaying and human-computer interaction. The results shows that the system can satisfy the demand of auxiliary decision support for ship collision avoidance operation.**

Keywords—embedded system; ship collision avoidance; collision risk index; AIS; decision support

I. INTRODUCTION (*HEADING 1*)

With the rapid development of modern economy, water transport has become increasingly busy and the occurrence of ship collision has become more and more frequent. Ship collisions not only bring the enormous economic losses, but also damage to the ecological environment irreversibly, especially for oil ship, liquefied petroleum gas ship, chemical ship and nuclear powered ship. Therefore, it is significant to study a new method of decision support for ship trajectory monitoring and collision avoidance operation. In recent years, Automatic Identification System (AIS) can share information between the nearby ships and provide with the operation of encountered ships in a real-time way. However, the above method is not qualified to give the comprehensive analysis in order to take effective actions to reduce the collision risk between the encounter ships. As a result, the AIS information is not fully utilized.

In recent years, many researchers are devoted to studying and making full use of AIS information to solve the collision problem, and have made some achievements. Considering that ship domain is an important factor that needs to pay attention to in ship collision avoidance, Chang et al. [1] proposed a geospatial approach to build ship domain maps that makes full use of information available from AIS; X. Wang [2] describes the application methods of using information provided by radar and AIS equipment to the analysis of ship collision avoidance, in the case of poor visibility; F. Zhu [3] puts forward the AIS information data mining, and emphasizes the necessity and feasibility of using the mined data in the analysis of ship's behavior and traffic flow; Z. Li [4] and J. Wu [5] both analyze the application of AIS information in the research of ship automatic collision avoidance, and conclude that by using AIS information we can solve the two issues, which are the acquisition problem of target's information and the exchange problem of collision avoidance information, respectively. The above results will promote the application of AIS information to ship collision analysis. However, the products of practical application that can be used for auxiliary control and decision support of ship collision avoidance have not been reported.

With the development of embedded technology, its application in ship collision avoidance will have a growing number of studies. If we select embedded technology combined with the AIS information, a new local intelligent system of decision-making support for ship collision avoidance can be constructed. The system will be able to provide timely support of accurate operation for ship collision avoidance. It can also provide with automatic storage and backtracking function for ship navigation log, which will bring revolutionary change on the navigational safety for ship.

Therefore, considering the actual requirements of the latest development of embedded technology and the perception of ship collision avoidance, this paper has conducted the research on the AIS-based embedded system for ship collision

978-1-4799-8694-1/11/$31.00

avoidance, with a view to make auxiliary decision for the collision avoidance operation when ships meet.

II. THE ANALYSIS OF SHIP ENCOUNTER SITUATION

A. The Analysis of Motion Vector

During the process of research on ship collision avoidance, the size and maneuverability of two ships can be negligible when the ships are far away. Then the two ships can be regarded as two moving particles with a certain velocity vector. So it can be placed in the geometric coordinate system to analyze the status of encounter ships, as shown in Figure 1 [4].

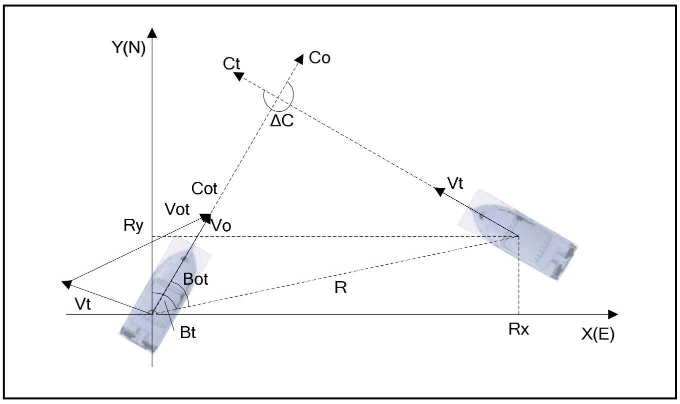

Figure 1: The moving vector diagram of encounter ships

The GPS position of the vessel is (λ_O , φ_O), the speed over ground (SOG) and course over ground (COG) is V_O and C_O respectively; the GPS position of target vessel is (λ_T , φ_T), the SOG and COG is V_T and C_T respectively. According to the relationship and calculating the two set of information, we can obtain (R_X , R_Y) in the coordinate system, relative distance (R), the relative speed with target vessel (V_{OT}), the relative course with target vessel (C_{OT}), the azimuth of target vessel (B_T), the relative azimuth with this vessel (B_{OT} , $0^\circ \le B_{OT} \le 180^\circ$).

Then the DCPA (Distance of the Closest Point of Approach) and TCPA (Time to the Closest Point of Approach) of encounter ships can be obtained. The expressions are as follows.

$$DCPA = R \times \sin(C_{OT} - B_T) \tag{1}$$

$$TCPA = \frac{R \times \cos(C_{OT} - B_T)}{V_{OT}} \tag{2}$$

B. The Division of Encounter Situation

According to the requirements of the rules and relevant knowledge of sailing vessels, the encounter situation of two vessels in sight of one another can be quantified and divided into the following parts:

- Head-on: Two ships meet each other in the opposite or nearly opposite course while there is a risk of collision. Quantification is expressed as $B_{OT} \le 5^\circ$ and $174^\circ \le \Delta C < 186^\circ$.
- Starboard crossing: Two ships head to cross while the target ship is located on the starboard side. According to the encounter angle, the situation can be divided into: A small crossing angle ($B_{OT} \le 45^\circ$ and $186^\circ \le \Delta C < 210^\circ$); A large crossing angle ($B_{OT} \le 125^\circ$ and $210^\circ \le \Delta C < 360^\circ$).
- Larboard crossing: Two ships head to cross while the target ship is located on the larboard side. According to the encounter angle, the situation can be divided into: A small crossing angle ($B_{OT} \le 45^\circ$ and $150^\circ \le \Delta C < 174^\circ$); A large crossing angle ($B_{OT} \le 125^\circ$ and $0^\circ \le \Delta C < 150^\circ$).
- Being overtaken: Other ships are overtaking from a direction more than 22.5° abaft the beam of this ship. Quantification is expressed as $V_O < V_T$, $B_{OT} \ge 112.5^\circ$, $0^\circ \le \Delta C < 90^\circ$ or $270^\circ \le \Delta C < 360^\circ$.
- Overtaking: $V_O > V_T$, $B_{OT} \le \arcsin(0.924 \times V_T / V_O)$, $0^\circ \le \Delta C < 90^\circ$ or $270^\circ \le \Delta C < 360^\circ$.

III. THE ANALYSIS OF SHIP COLLISION AVOIDANCE MODEL BASED ON EMBEDDED SYSTEM

In order to realize the collision forewarning function in the embedded system for ship collision avoidance, it needs the concept of risk degree of collision to measure the collision possibility of current encounter situation, and to judge whether it needs to forewarning according to the threshold value division. In this paper, the risk degree of collision refers to the microscopic risk, which means it comprehensively evaluates on the both specific circumstances of meeting ships, such as navigation area, visibility, ship, cargo, the quality of the drivers and other factors.

As the analysis of collision avoidance needs to be achieved through the embedded system, the amount of calculation cannot be too large. Then it needs a simple and effective evaluation mathematics model of ship collision dangerous degree that adapt to the operational ability of embedded system. So, this system puts the thought and method of current several typical evaluation models [6] into consideration, and determines the use of fuzzy membership degree to construct a fuzzy evaluation model of ship collision risk. This paper select the DCPA, relative distance (R), TCPA, the azimuth from this vessel to target vessel ΔB ($\Delta B = B_T - B_O$, $B_O = C_O$) and the speed ratio K ($K = V_O / V_T$) as the main factors of evaluation. Among them, membership functions of R and DCPA reflect the space collision risk; membership function of TCPA reflects time collision risk. They reflect the risk of two encounter ships all from the perspective of the geometric relationship. Membership degree of K is a reflection of the difficulty of collision avoidance, the principle that both reflect collision difficulty is: When the collision risk between two ships exists, they can be out of danger easily as long as simple small amplitude action is taken, we can consider two ships to be little danger of collision; On the contrary, if it needs early and substantial action to avoid collision, the situation should be considered to be high-risk. Meanwhile, the value of ΔB and K have an effect on the action to avoid collision. Membership function definitions of collision risk corresponding to the above evaluation factors are as follows [6, 7, 8]:

1) The membership function of DCPA:

$$U_{DCPA} = \begin{cases} 1 & |DCPA| \le d_1 \\ \frac{1}{2} - \frac{1}{2}\sin[\frac{\pi}{d_2 - d_1}(|DCPA| - \frac{d_1 + d_2}{2})] & d_1 < |DCPA| \le d_2 \\ 0 & d_2 < |DCPA| \end{cases} \quad (3)$$

$$d_1 = SDA \cdot N$$

$$d_2 = K \cdot d_1$$

where d_1 indicates the minimum distance of passing safely; d_2 indicates a safe encounter range; N is the immediate visibility, and N=1.0 for AIS system; K is the coefficient determined by the factors as the instability of ship state and the two ships' incoordination, and generally 1.5-2.0, K=2.0 in this paper.

SDA is the fuzzy distance when the ship's sailors is operating. According to the Goodwin model [10], it is expressed as :

$$SDA = D(\Delta B) + K_1 + K_2$$

K_1 is the influence of visibility on the SDA, K_1=0 for the AIS system; K_2 is the influence of navigation area on the SDA, and is 0 along the coast or 0.2 in the ocean, K_2=0 in this paper.

The process of $D(\Delta B)$ is shown as follows:

$$D(\Delta B) = \begin{cases} 1.1 - \frac{\Delta B}{180^\circ} \times 0.2 & 0^\circ \le \Delta B \le 112.5^\circ \\ 1.0 - \frac{\Delta B}{180^\circ} \times 0.4 & 112.5^\circ < \Delta B \le 180^\circ \\ 1.0 - \frac{360^\circ - \Delta B}{180^\circ} \times 0.4 & 180^\circ < \Delta B \le 247.5^\circ \\ 1.1 - \frac{360^\circ - \Delta B}{180^\circ} \times 0.4 & 247.5^\circ < \Delta B \le 360^\circ \end{cases}$$

2) The membership function of R:

$$U_R = \begin{cases} 1 & R \le r_1 \\ \frac{1}{2} - \frac{1}{2}\sin[\frac{\pi}{r_2 - r_1}(R - \frac{r_1 + r_2}{2})] & r_1 < R \le r_2 \\ 0 & r_2 < R \end{cases} \quad (4)$$

$$r_1 = DLA$$

$$r_2 = Arena$$

where r_1 indicates the distance of ship collision; r_2 indicates the distance of taking attention to target ship; DLA indicates the distance of taking action to avoid collision at latest ,that is the point of the last minute action; the expression of Arena is:

$$Arena = V_{OT} \cdot (T + \frac{d_2}{V_{OT}}) = d_2 + V_{OT} \cdot T$$

3) The membership function of TCPA:

The process of $D(\Delta B)$ is shown as follows:

$$U_{TCPA} = \begin{cases} 1 & |TCPA| \le t_1 \\ \left|\frac{t_2 - |TCPA|}{t_2 - t_1}\right|^{3.03} & t_1 < |TCPA| \le t_2 \\ 0 & t_2 < |TCPA| \end{cases} \quad (5)$$

where t_1 indicates the time of ship collision; t_2 indicates the time of taking attention to target ship. Usually considered 6-8 nautical miles between ships is free driving stage for ship, for the sake of safety, this paper sets 8 nautical miles as the distance between ships beginning to form the collision situation. Then we set the time required to sail from 8 nautical miles between ships to the closest point of approach as t_2. The expression is:

$$t_1 = \begin{cases} \frac{\sqrt{DLA^2 - DCPA^2}}{V_{OT}} & DCPA \le DLA \\ \frac{DLA - DCPA}{V_{OT}} & DCPA > DLA \end{cases} \quad (6)$$

$$t_2 = \frac{\sqrt{8^2 - DCPA^2}}{V_{OT}}$$

4) The membership function of ΔB :

$$U_{\Delta B} = \frac{1}{2}\left[\cos(\Delta B - 19^\circ) + \sqrt{\frac{440}{289} + \cos^2(\Delta B - 19^\circ)}\right] - \frac{5}{17} \quad (6)$$

5) The membership function of K:

$$U_k = \frac{1}{1 + \frac{W}{K\sqrt{K^2 + 1 + 2K\sin C}}} \quad (7)$$

where C is the collision angle ($0^\circ \le C \le 180^\circ$); W is a constant, and is 2.0 in this paper.

Based on the above definition, marine risk assessment model are as follows:

Assuming that DCPA, TCPA, R, ΔB and K are selected as the 5 main factors of evaluation and U_{DCPA}, U_{TCPA}, U_R, $U_{\Delta B}$ and U_K are the degree membership of the target ship's parameters for the risk and belong to [0, 1], then model expression of the collision risk index (CRI) for two ships is:

$$f\left(U_{DCPA},U_{TCPA},U_R,U_{\Delta B},U_K\right)= a_{DCPA}U_{DCPA}+a_{TCPA}U_{TCPA}+a_RU_R+a_{\Delta B}U_{\Delta B}+a_KU_K \quad (8)$$

where a_{DCPA}, a_{TCPA}, a_R, $a_{\Delta B}$, a_K are the weight of target vessel, belong to the [0, 1], and the sum of them is 1.

IV. The Design of Embedded System For Ship Collision Avoidance

According to the characteristics of ship operation, the main functions of the system to satisfy the demand of assistant decision for ship collision avoidance can be designed as: intelligent analysis, forewarning prompt, operation suggestion, and data backtracking.

Intelligent analysis: According to the status information from AIS as the ship's longitude, latitude, heading course and speed, the encounter situation type, DCPA, TCPA, CRI and other analysis results can be calculated by the formula (1) - (8). With converting the state data of navigation to the meeting state information, the analysis result will be displayed on screen. It is convenient for the driver to have an intuitive understanding of the encounter state.

Forewarning prompt: CRI can be divided into three warning levels, which are free navigation stage without risk, potentially dangerous stage with low risk, emergency stage of collision avoidance with high risk. Based on CRI obtained by the intelligent analysis and threshold range, different risk types of meeting ship will be displayed with different colors so that it can give forewarning prompt to the seafarers. In the situation with high risk, the system will alarm with buzzer.

Operation suggestion: In the emergency stage with high risk, the system can give advice for collision avoidance operation. According to TCPA, DCPA and other encounter state information, the system will advance the suggestion on speed changing, course changing, or both of them. The suggestion refers to the requirements stated in article 8, chapter 2 of "Convention on the International Regulation for the preventing Collision at Sea (1972)" and the usual practice for preventing collisions at sea. The specific quantitative criterion is on the basis [9].

Data backtracking: The system provides the function of automatic storage and backtracking for ship navigation log. The backtracking function makes the ship navigation state changes become intuitive and transparent, and also provides original data to analyze whether operation for avoiding the collision is correct and effective.

The working process of the system: With receiving the AIS information in real time, the system will store the information and calculate the safe distance. When the distance is more than 8 nautical miles, the target ship is at stage of free driving without collision risk, then there is no needs to store the calculated results; When the distance between ships is less than 8 nautical miles, CRI should be calculated by the formulas (1) - (8), and the results will be stored in the database. At the same time, current information of the ship and encounter ships should be displayed through the system interface in real time. The system will issue a warning according to the risk type and give advice of operation to avoid collision. When we need to query the historical information, it can be provided by data backtracking function of the system. Then the analysis result of the driver' operation behavior can be obtained by historical information, and can help find the cause of the accident

V. System Implementation and Testing

A. Algorithm Testing

The algorithm testing data of the system comes from [10]. The ship is sailing in open water with good visibility as the data of ship encounter status are from the AIS. In the test, the course and speed of the ship is 0° and 15 *kn* (10 *kn*, when the ship is being overtaken by other ship), respectively. The time needed for the ship to rotate by 90° with full rudder is 2.0 min, the ship length is 100 m, and the weight given to each parameter is set to be 0.2. The motion state parameters of target ships and the calculated CRI are shown in the following table.

TABLE I. THE MOTION STATE PARAMETERS OF THE TARGET SHIP

Target Ship	**The Motion State Parameters of Target Ships**			
	***Course* (°)**	***Speed* (*kn*)**	***Azimuth* (°)**	***Distance* (*n mile*)**
1	180	15	5	5
2	265	15	45	4
3	100	15	315	4
4	100	15	315	2.2
5	0	8	356	1.5
6	5	15	183	1.5
7	5	15	183	1.2

TABLE II. THE CRI OF TARGET SHIPS

Target Ship	**The Calculated Results of State Parameters**			
	Situation	***DCPA* (*n mile*)**	***TCPA* (*h*)**	***CRI***
1	Head on	-0.436	0.166	0.491
2	Starboard (large angle)	-0.174	0.181	0.514
3	Larboard (large angle)	0.349	0.173	0.445
4	Larboard (large angle)	0.192	0.095	0.541
5	Overtaking	0.105	0.214	0.690
6	Being overtaken	0.307	0.287	0.368
7	Being overtaken	0.246	0.230	0.404

The results show that different situation of ship encounter has different risk degree of collision. By comparison of the

978-1-4799-8694-1/11/$31.00 © 2015 IEEE

data, $|DCPA_3| > |DCPA_4|$, $|TCPA_3| > |TCPA_4|$ and $CRI_3 < CRI_4$, while the difference between Target ship 3 and Target ship 4 is only the distance. It tallies with the actual situation that the nearer ship has a higher risk under the same conditions with other ships. The situation of Target ship 6 and Target ship 7 is the same. For Target ship 2 and Target ship 3, both have the same distance and speed and the difference of course and azimuth. Then we can see that $|DCPA_2|$ is significantly much less than $|DCPA_3|$ while $|TCPA_2|$ was not so far different from $|TCPA_3|$. So the result of $CRI_2 > CRI_3$ tallies with the actual situation that the target ship on the starboard side is more dangerous than on the larboard side. Other groups of data can also be compared and analyzed ,and the whole basically conforms to the reality and the "Convention on the International Regulation for the preventing Collision at Sea (1972)".

B. System Implementation

The embedded processor of this system utilizes the ARM platform, which is the S3C6410 chip from Samsung, SQLite3 database to realize the data storage, and QT to build an interactive interface. Hardware structure is shown in Figure 2. The system for collision avoidance centers on embedded platform and is connected with the AIS module, GPS module, GPRS communication module, touch screen etc. The AIS module receives target ships' information and broadcasts own ship' information by very high frequency (VHF) channel. The GPS module percepts of the ship's course and speed state information. GPRS module realizes the data communication with remote control center. The touch screen realizes local display and interaction with users. It can also set aside other serial port to obtain the sensing data required for other local monitoring.

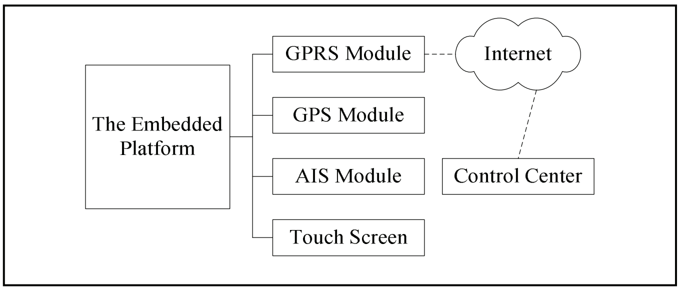

Figure 2: The structure of the embedded system for ship collision avoidance

Figure 3 is the interface of displaying ships' encounter situation in the embedded system. 7 of the displayed target ships are the ships in table □, and other 2 without collision risk are added for showing encounter situation more comprehensively. In the coordinate system of north as Y axis and east as X axis, it shows motion state relations (relative position and each ships' heading indicated by the arrows) between own vessel and encounter ships within 8 nautical miles, and collision risk types (green for the free navigation stage, yellow for potential dangerous stage, red for emergency avoidance stage). It intuitively reflects around the ship navigation environment and is convenient for the seafarers to make the right judgments on the navigation route.

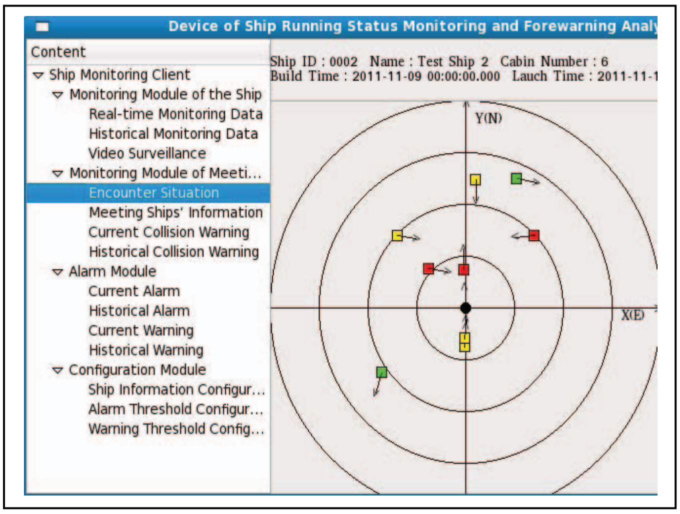

Figure 3: The interface of displaying ships' encounter situation in the embedded system

VI. Conclusion

By combining embedded technology with AIS information, this paper proposes a specific realization method of embedded ship collision avoidance system. Its main role is to visually display the ship's navigation state for the seafarers and to give the collision forewarning and operation plan, during the collision avoidance process of encounter ships. In a dangerous situation of multi ships encounter, the seafarers can select the key ship to avoid according to the degree of collision risk. Meanwhile, the system also has the function of storing and backtracking, it is easy to query the historical information and helpful for analyzing the cause of the accident. The system provides the seafarers with a new method of encounter ships' auxiliary operation and a better understanding of the navigation environment. That would make the ship navigation safety, and reduce the occurrence of collision accident.

Acknowledgment

This paper has been supported by Fund of Hubei Inland Shipping Technology Key Laboratory (NHHY2014006). Financially supported by self-determined and innovative research funds of WUT (2015-zy-089).

References

[1] S. Chang, D. Hsiao, and W. Wang, "AIS-based delineation and interpretation of ship domain models," OCEANS 2014 - TAIPEI, Taipei, 7-10 April 2014, pp. 1-6

[2] X. Wang, "Several experience of ship collision avoidance," 2nd International Conf. Consumer Electronics, Communications and Networks (CECNet), China:Yichang, 21-23 April 2012, pp. 2838- 2841.

[3] F. Zhu, "Mining ship spatial trajectory patterns from AIS database for maritime surveillance," 2nd IEEE International Conf. Emergency Management and Management Sciences (ICEMMS), Beijing, 8-10 August 2011, pp. 772 - 775.

[4] Z. Li, A Study of Auxiliary Decision-making for Ship Collision Avoidance Based on AIS and ECDIS, Dissertation, China: Wuhan University of Technology, April 2010.

[5] J.Wu, Key Technology Research on the Integrated Use of Shipping Logistics Information Based on AIS along the Artery of the Yangtze River, Dissertation, China: Wuhan University of Technology, December 2012.

[6] Y. Lu, Research on Ship Collision Avoidance System Based on ECDIS, Dissertation, China: Harbin Engineering University, December 2011.

[7] W. Li, A Study of Intelligent Decision on Single Ship Collision Avoidance in Open Waters, Dissertation, China: Dalian Maritime University, May 2013.

[8] Y. Wang, Study on Theory and Method of Ship Collision Avoidance Decision Making, Dissertation, China: Shanghai Maritime University, December 2004.

[9] X. Bi, Study on Ship's Collision Risk Index and Collision Avoidance Model, Dissertation, China: Dalian Maritime University, August 2000.

[10] H. Wu, Design and Implementation of Ship Collision Avoidance Terminal Based on AIS and Radar information fusion, Dissertation, China: Harbin Engineering University, March 2013